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Volatility of the interest rate, debt and firm investment: Dutch evidence

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Abstract

This paper analyzes the joint impact of the interest rate volatility and debt on firm investment. We derive an investment model taking account of the risk attitude of the owners of the firm. Using a panel of Dutch listed firms in the period of 1984–1995, we find that the cross-effect of the interest rate volatility and debt on investment is positive. This effect is more important for highly indebted firms than for less-indebted firms. The results are robust to different measures for the interest rate volatility. We interpret this finding by the tradeoff between the effect of the interest burden and the effect of debt revaluation. © 2002 Elsevier Science B.V. All rights reserved.

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Keywords: Firm investment; Interest rate volatility; Debt; Uncertainty measure

1. Introduction

The effect of uncertainty on firm investment attracts a lot of attention in the literature. Under the assumption of perfect market competition in combination with a constant returns to scale technology the marginal profitability of capital is a convex function of uncertainty variables. By Jensen's inequality uncertainty has a positive effect on investment (Hartman, 1972; Abel, 1983). Modeling investment decisions of a firm by assuming that the firm holds a call option on future cash flows predicts a positive threshold effect, i.e. the increases in uncertainty increase the threshold that triggers investment (Dixit and Pindyck, 1994). However, the effect of uncertainty on the level of investment is ambiguous. Caballero (1991) documents that irreversibility, one important assumption of the real options theory of investment, is a necessary but not a sufficient condition that leads to a negative correlation between investment and uncertainty. Caballero proves that

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only if irreversibility is assumed in combination with decreasing returns to scale or imperfect competition uncertainty has a negative effect on investment. Abel and Eberly (1999) distinguish between the user cost effect (short run) and the hangover effect (long run) of irreversibility on investment. In the long run, irreversibility may result in a higher capital stock of the firm. Bar-Ilan and Strange (1999) argue that within the real options framework a positive effect of uncertainty on investment may be present if the intensity of investment is taken into account. In addition, the risk-attitude of the firm (Aizenman and Marion, 1999; Nickell, 1978), the degree of financial constraints faced by the firm (Greenwald and Stiglitz, 1990), and the source of uncertainty (Huizinga, 1993) are found to be significant factors that influence the sign of the investment–uncertainty relationship. Especially the latter distinction is relevant to our study, since we are interested in the uncertainty surrounding the cost of debt. Huizinga finds a negative sign for cost uncertainty variables (the real wage rate, the real price of material inputs) and a positive sign for profit-related variables (the output price and the profit rate). All in all, the unclear-cut prediction of the sign of uncertainty effects implies that the investment–uncertainty relationship relies more on empirical tests.

This paper extends the empirical research on the effect of uncertainty on firm investment as follows: First, we link the interest rate uncertainty with firm investment in a structural way. We start with the utility function of the owners of the firm to derive a neoclassical-type investment model that contains the second moment of the interest rate. In the literature, the way of linking uncertainty measures with investment models has been using the reduced form of investment equations. Secondly, we start from the idea that the financial structure of the firm is relevant to the impact of the interest rate volatility¹ on investment. Especially we address the sensitivity of investment to the interest rate volatility, taking into account the effect of leverage. The argument is relatively simple. Suppose we have a firm, financed by equity and debt. As is known, high inflation, which implies high volatility of inflation and nominal interest rates,² has an impact on the financial structure of the firm in real terms. A higher interest rate will lead to a higher interest rate burden on the one hand, but it lowers the real value of debt on the other. As Ritter and Warr (1998) show this generally leads to a wealth transfer from the owners of debt to equity owners. This gives the firm an incentive to invest as long as the reduction of the real value of debt exceeds the increase in the interest burden. This phenomenon exists for all levered firms. Especially firms with a high leverage may experience a positive cross-effect of debt holdings and the interest rate volatility. For firms holding a lower amount of debt, the benefits from the reduction of the real debt probably are too low to cover the increase in interest payments. In any case, we expect the cross-effect of debt holdings and the interest rate volatility to be an important determinant of firm investment.

The paper is structured as follows. Section 2 briefly presents an investment model, in which we introduce the interest rate uncertainty by taking account of the risk attitude of the owners of the firm. Section 3 explains the measurement of the volatility of the interest rate. Empirical results are discussed in Section 4. Section 5 summarizes and concludes the paper.

¹ In this paper, uncertainty and volatility are used interchangeably.

² For the positive relationship between the inflation rate and its variability, see Chowdhury (1991) and the cited literature there.

2. Modeling interest rate uncertainty in an investment equation

The optimal investment trajectory of a firm is the solution to the firm's intertemporal optimization problem. The objective function of the firm from the point of view of managers may differ from that of shareholders if agency costs are accounted for. If we ignore the agency costs between the shareholders and the managers of the firm, the objective function for deriving the optimal investment rule of the firm is closely related to the utility optimization problem of the shareholders of the firm. The investment behavior of shareholders cannot be separated from their consumption behavior if payoffs from investing are uncertain because the optimal choice differs across individuals in the case of uncertainty. Therefore, we adopt the dynamic objective function for the firm under uncertainty of Nickell (1978) which takes the form:³

$$V_j(0) = \int_0^{\infty} e^{-rt} [E_0(CF_{jt}) - \theta \text{Var}(CF_{jt})] dt \quad (1)$$

Where $V(0)$ is the discounted present value of the firm at time $t=0$. E_0 is the expectation operator based on the information available at time $t=0$. r is the constant discount rate faced by the firm, which is measured in real terms. CF_{jt} is the cash flow generated by firm j at time t . $\text{Var}(CF_{jt})$ is the variance of cash flow, which is the measure of the amount of the risk that is associated with the future income stream. θ is the market price of risk. We assume that θ is positive, which is equivalent to assuming a risk-averse attitude of the owners of the firm. Eq. (1) states that the value of the firm is equal to the expected present value of the future cash flow generated by the firm less the total cost of the risk associated with that particular cash flow. In this paper, we derive a neoclassical-type investment model using the objective function (1). The “normal” objective function of the firm in the neoclassical investment model is:

$$V_j(0) = \int_0^{\infty} e^{-rt} [E_0(CF_{jt})] dt \quad (2)$$

In Eq. (2), both the market price of risk and uncertainty variables are missing. This is due to the assumption of risk neutrality of the firm. To derive the investment equation, the firm is assumed to maximize (Eq. (1)) subject to the capital accumulation process (Eq. (3)) and the cash flow identity (Eq. (4)). Here we define cash flow as operating profits minus interest payments plus the depreciation of the capital stock.

$$\dot{K}_t = I_t - \delta K_{t-1} \quad (3)$$

$$CF_t \equiv p_t F(K_t, L_t) - w_t L_t - p_t A(K_t, I_t) - p_t I_t - i_t B_t(I_t, IW_t) + \delta K_{t-1} \quad (4)$$

where $F(K_t, L_t)$ is the production function. K_t , L_t , and I_t are the capital stock, the labor input, and the gross investment of the firm at time t , respectively. δ is the constant rate of

³ For the derivation of the dynamic objective function for firms under uncertainty, see Nickell (1978, pp. 160–163), and his Appendix, proposition 2.

depreciation of capital. w_t and p_t are the nominal wage rate and the output price (we assume that the price of capital goods equals the price of output). $A(K_t, I_t)$ is the internal convex cost function of adjusting the capital stock. $B_t(I_t, IW_t)$ is the net borrowing of the firm and i_t is the interest rate at time t . Notice that the net borrowing of the firm is a function of the current investment I_t and a vector IW_t that represents the internal source of investment financing available at time t . And $(\partial B_t(I_t, IW_t))/\partial I_t > 0$, $(\partial B_t(I_t, IW_t))/\partial IW_t < 0$. The specification of the borrowing function allows us to account for many factors, such as collateral, the probability of success of the investment project, and so on, which are especially important when capital markets are imperfect.

Assume that the firm is operating in competitive product markets and the prices of goods are given. The only source of uncertainty is the interest rate. By using the conventional quadratic adjustment cost function and a linear borrowing function, we obtain the following investment equation:⁴

$$\frac{I_t}{K_t} = \beta_0 + \beta_1 i_t + \beta_2 \text{Var}(i_t) \times B_t + \varepsilon_t \quad (5)$$

where ε_t is the normally distributed error term and the β 's are parameters. $\text{Var}(i_t)$ is the variance of the interest rate at time t .

Eq. (5) provides a theoretical relationship between investment and the volatility of the interest rate. Since we are interested in the interaction between the interest rate uncertainty and debt in affecting firm investment, the own effect of the interest rate volatility and the own effect of debt should be isolated from the cross-effect of the two. Therefore, the empirical specification of the investment equation is:

$$\frac{I_t}{K_t} = f_j + f_t + \beta_1 i_t + \beta_2 \text{Var}(i_t) \times B_t + \beta_3 \text{Var}(i_t) + \beta_4 B_t + \varepsilon_t \quad (6)$$

where f_j, f_t are firm effects and time effects. β_3 and β_4 represent the marginal effects of the interest rate volatility and debt on the investment-to-capital ratio, respectively. β_2 gives the sensitivity of the investment-to-capital ratio to the joint effect of the interest rate volatility and debt. In estimations, $\text{Var}(i_t)$ and B_t are scaled by the capital stock to eliminate size effects.

3. Measuring the interest rate volatility

An uncertainty measure should ideally be a forward-looking proxy for expectations of future variables, which can be obtained by using survey techniques. Guiso and Parigi

⁴ Appendix A provides more details on the derivation of the investment model.

(1999) provide an example to quantify uncertainty using survey data in the empirical literature. However, probably due to the difficulties of obtaining high quality survey data, much empirical research on the effect of uncertainty applies ex-post measures. Historical data is used to construct the variance of the underlying uncertainty variables. If the variance is assumed to be constant over time, the normal statistical standard deviation is computed as the uncertainty measure (Pindyck, 1986). A bit more sophisticated method in this class is to compute the variance of the unpredictable part of the stochastic process that governs the variable of concern (Ghosal and Loungani, 1996, 2000). Taking account of the time dependence of the variance, the Generalized AutoRegressive Conditional Heteroskedasticity (GARCH)-type modeling of volatility can be applied (Huizinga, 1993). Finally, if data is continuous, stochastic differential equations, for instance the geometric Brownian motion, are more useful (Caballero and Pindyck, 1996).

Since survey data is not available, in the current study we adopt three of the above-mentioned ex-post methods: the ARCH modeling of volatility, the variance of the unpredictable part of stochastic processes, and the normal variance.

We first construct the measure of the interest rate volatility by the variance of the unpredictable part of the firm interest rate. The firm-level interest rate is the ex-post interest rate paid by the firm. It was constructed based on the publication of *Jaarboek van Nederlands Ondernemingen*, which covers 82 listed Dutch manufacturing firms during 1984–1995. The series of the firm interest rates is stationary according to the Augmented Dickey-Fuller (ADF) Unit Root test. The firm interest rate is assumed to follow a first order autoregressive (AR(1)) process. We estimated the AR(1) process of the interest rate for each firm separately and saved the estimated residuals. Then the variance of the residuals is computed as the measure of the interest rate uncertainty. It is assumed that firms update every year their expectations on the future development of the interest rate using the whole historical track of the interest rate process. Therefore, we utilize all the past information of the residuals to calculate the variance of the residuals. For example, to compute the volatility measure for the year 1987, we use the residuals at 1987, 1986, 1985;⁵ for the year 1988, the residuals at 1988, 1987, 1986, 1985 are used, and so on. The second volatility measure for the firm interest rate is constructed by the normal variances of the firm interest rate. Similarly, the variance of the firm interest rate is computed based on all available past information.

To check the robustness of the firm-level estimation results, we construct two aggregate volatility measures for the interest rate using the market interest rate. We expect the fluctuations of the market interest rate to reflect the changes in the firm interest rates. The data on the market interest rate is the 10-year Dutch government bond rates from 1986:5 to 1998:10 (see De Nederlandsche Bank).⁶

⁵ The data set starts from 1984. The series of the estimated residuals starts from 1985.

⁶ In order to use the 10-year government bond rate as the market rate of interest, we extracted monthly observations of 1984, 1985 and the first four months of 1986 for the 10-year bond rate using the observations of five newest government bond contracts on the basis that they show the same time path.

Table 1

Estimation results for the ARCH(1) model

$$i_t = \tau_0 + \tau_1 i_{t-1} + \varepsilon_t$$

$$\sigma_t^2 = \varphi_0 + \varphi_1 \varepsilon_{t-1}^2$$

Parameter	Coefficient	Standard error
τ_0	-0.0133	0.0782
τ_1	0.9969	0.0113
φ_0	0.0316	0.0053
φ_1	0.2483	0.1162
Adjusted <i>R</i> -squared	0.9683	

Data source: De Nederlandsche Bank.

Explanations of variables: i : the interest rate; σ^2 : the conditional variance of the interest rate.

The first aggregate volatility measure is the conditional variance of the market interest rate estimated from the ARCH(1) model. A first order autoregressive process (AR(1)) is used as the conditional mean equation for the ARCH(1) model. The structure of the ARCH(1) model we used to estimate the conditional variance of the interest rate is:

$$i_t = \tau_0 + \tau_1 i_{t-1} + \varepsilon_t \quad (7)$$

$$\sigma_t^2 = \varphi_0 + \varphi_1 \varepsilon_{t-1}^2 \quad (8)$$

where i is the interest rate. σ_t^2 is the conditional variance of the interest rate at time t . $\varphi_0 > 0$, $\varphi_1 \geq 0$. ε_t is the error term, $E(\varepsilon_t) = 0$ and $\text{Var}(\varepsilon_t) = 1$. Table 1 reports the estimation results for the ARCH(1) model.

As the result of estimating the ARCH(1) model, we obtain the series of the conditional variance of the interest rate with monthly observations. In order to match these with our annual investment data at hand, we use the median of the distribution of the conditional variance over each 12-month period as the proxy for the conditional volatility of the market interest rate for that year.

The second aggregate volatility measure of the interest rate is constructed as the variance of the unpredictable part of the market interest rate. The original series of the market interest rate displays nonstationarity. Consequently, we work with the first order difference of the series of the market interest rate. The interest rate is again assumed to follow an AR(1) process. The residuals from estimating the AR(1) process for the first difference of the interest rate are saved for each year. The volatility measure is constructed by computing the variance of the residuals for each year.

4. Evidence on the interaction between the interest rate volatility and debt

In this section, we analyze the impact of the cross-effect of the interest rate volatility and debt on firm investment. Being consistent with the interest rate data, the data on fixed

investment, the capital stock, and debt are constructed from a balanced panel consisting of 82 listed Dutch manufacturing firms over the period of 1984–1995. All data is taken from the publication *Jaarboek van Nederlandse Ondernemingen*.

Table 2 gives summary statistics for the variables used in the estimations, including the constructed volatility measures for the interest rate. As shown by the table, high-debt firms have a larger investment-to-capital ratio as compared to both the whole sample and low-debt firms. Less-indebted firms on average pay a higher interest rate than high-debt firms. The mean value of the market interest rate is 7.29 (not reported), which is higher than the average firm interest rate in the sample period. The standard deviation of the market interest rate is relatively low (0.98) as compared to that of the firm interest rates. The average amount of borrowing held by low-debt firms is not that different from that borrowed by its counterpart. However, the distribution of debt is skewed as shown by the standard deviations.

Table 3 reports fixed effects estimation results for the whole sample. Time dummies are added in the estimations, most of them turn out to be insignificant. To obtain some insight into the economic significance of the estimates, the standardized regression coefficients are computed in case the unstandardized estimates are statistically significant. As we can see from the table, the level effect of the interest rate is very important for the whole sample. The increases in the interest rate depress firm investment effectively. The

Table 2
Descriptive statistics: (unit: 10⁶ Guilders)

	Whole sample		High-debt firms		Low-debt firms	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Investment/capital	0.19	0.17	0.21	0.19	0.18	0.14
Firm interest rate	3.71	2.14	3.59	2.31	3.82	1.96
Debt	1586.24	4606.24	1599.98	5448.41	1572.49	3578.69
Volatility measures						
Measure 1	1.35	2.21	1.41	1.76	1.28	2.58
Measure 2	1.73	2.44	1.87	2.33	1.59	2.53
Measure 3	0.04	0.01	0.04	0.01	0.04	0.01
Measure 4	0.04	0.03	0.04	0.03	0.04	0.03
Volatility * Debt						
Measure 1 * Debt	1982.25	7810.39	2938.37	10722.19	1026.12	2317.63
Measure 2 * Debt	2169.39	8901.38	3017.99	12153.74	1320.81	3086.57
Measure 3 * Debt	64.89	194.78	65.69	231.79	64.09	149.17
Measure 4 * Debt	54.91	188.47	56.21	227.95	53.61	138.48
Observations	738	738	369	369	369	369

Data source: *Jaarboek van Nederlands Ondernemingen*.

The number of firms in the sample is 82, the sample period is 1984–1995.

Measure 1: The variance of the unpredictable part of the firm interest rate. Measure 2: The variance of the firm interest rate. Measure 3: The conditional variance of the market interest rate from estimating the ARCH(1) model. Measure 4: The variance of the unpredictable part of the first difference of the market interest rate.

Table 3

Fixed effects estimation results: whole sample

$$\frac{I_t}{K_t} = f_j + f_i + \beta_1 i_t + \beta_2 \text{Var}(i_t) \times B_t + \beta_3 \text{Var}(i_t) + \beta_4 B_t + \varepsilon_t$$

Regressor	Firm interest rate		Market interest rate	
	Measure 1	Measure 2	Measure 3	Measure 4
i_t	−0.0231 <−15.8817> −0.2837	−0.0219 <−15.5418> −0.2689	−0.0215 <−16.1008> −0.2641	−0.0228 <−16.0485> −0.2801
$\text{Var}(i_t) \times B_t$	1.97E−09 <2.6467> 0.0883	−2.20E−10 <−1.2891> 0.0765	6.84E−08 <4.6567> 0.0765	3.95E−08 <4.3466> 0.0427
$\text{Var}(i_t)$	0.0078 <2.9918> 0.0986	0.0059 <2.8414> 0.0825	0.1686 <1.4978> −0.0127	−0.0849 <−1.9253> −0.0127
B_t	−5.59E−10 <−0.3318>	1.17E−09 <0.6844>	−1.54E−09 <−0.9090>	2.51E−09 <1.3776>
Coefficient test (Wald)	$\beta_2 = \beta_3 = 0$	$\beta_2 = \beta_3 = 0$	$\beta_2 = \beta_3 = 0$	$\beta_2 = \beta_3 = 0$
F-statistic	22.7715**	4.1201*	17.5075**	9.5334**
Adjusted R-squared	0.7025	0.6983	0.7071	0.7012

Data source: *Jaarboek van Nederlands Ondernemingen*.

The number of firms in the sample is 82, the sample period is 1984–1995.

White heteroskedasticity-consistent *t*-statistics are in brackets.Bold figures below *t*-statistics are the standardized regression coefficients.

Measure 1: The variance of the unpredictable part of the firm interest rate. Measure 2: The variance of the firm

interest rate. Measure 3: The conditional variance of the market interest rate from estimating the ARCH(1) model.

Measure 4: The variance of the unpredictable part of the first difference of the market interest rate.

Explanations of variables: I/K : the investment-to-capital ratio; i : the interest rate; B : debt; $\text{Var}(i)$: the variance of the interest rate.

* Significant at the 5% level.

** Significant at the 1% level.

magnitude of the effect of the interest rate on investment does not significantly differ across uncertainty measures. On average, an increase in the interest rate of 1 standard deviation leads to an expected decrease in the investment to capital ratio by 0.27 standard deviations holding other explanatory variables constant. Debt alone does not significantly affects investment when all firms are pooled together. The estimated coefficient of the volatility measure for the interest rate is significant in three out of four cases, depending on the definition of the volatility measures. However, the relationship between the interest rate uncertainty and investment with respect to the sign of the uncertainty effect is ambiguous. The cross-effect of the interest rate volatility and debt is highly significant in three out of four cases, indicating that debt does affect firm investment through the fluctuations in the interest rate. Noticing that when it is significant, the cross-effect has a positive sign on average, the sample firms respond to the interaction between the interest rate volatility and debt by increasing investment. The average size of the impact of the

cross-effect is 0.07, indicating that 1 standard deviation increase in the interaction between debt and the volatility of the interest rate leads to an increase in the investment to capital ratio by 0.07 standard deviations. This might be explained by the fact that when the volatility of the interest rate is high (implying a higher inflation), the levered firms may benefit from the reduction of the real value of debt. When the debt revaluation effect denominates the increased interest burden, the firm will probably increase investment expenditure.

The estimation results for the whole sample show that the sample firms on average respond to the combined effect of debt and the interest rate volatility by increasing investment. However, it might be possible that firms with different debt positions respond to this cross-effect differently because the debt revaluation effect is expected to be different between high- and low-debt firms. To further test the debt revaluation effect of the interest rate volatility, we split the whole sample into highly and less-indebted firms and repeat the regressions for these two sub-groups. To avoid time-variant sample partition, we calculated the average debt and the average capital stock over the sample period for each firm and then computed the ratio of the average debt to the average capital stock for each firm. The sample is split by the median of the ratio of the average debt to the average capital stock. Tables 4 and 5 report the estimation results for high- and low-debt firms, respectively.

We should keep in mind that the cross-effect of debt and the interest rate volatility runs through two channels. First, an increase in volatility will increase the interest rate burden. Secondly, higher interest rate volatility will likely decrease the real value of debt holdings, yielding to a wealth transfer from bondholders to equity holders. The latter effect might be more important for highly indebted firms. Focusing on the firm-level volatility measures, we notice from Table 4 that when it is significant, the estimated coefficient of the cross-effect has a positive sign for high-debt firms. However, for low-debt firms Table 5 shows that both firm-level uncertainty measures are highly significant with a negative sign. These results imply that the debt revaluation effect is an important mechanism for highly indebted firms. The increases in the interest burden due to the increases in the interest rate volatility may be offset by the debt revaluation effect. On the other hand, the negative and significant cross-effect suggests that the increase in the interest burden is more important for less-indebted firms. When the impact of the interest burden dominates the debt revaluation effect, less-indebted firms may cut investment facing high interest rate volatility.

As robustness tests, we repeat the estimations using aggregate uncertainty measures. Columns (3) and (4) of Table 4, and columns (3) and (4) of Table 5 show the estimation results for high- and low-debt firms, respectively. For highly indebted firms, the estimated coefficient of the cross-effect is highly significant with the positive sign for both aggregate uncertainty measures. The estimated coefficient of the cross-effect for low-debt firms is insignificant when the conditional variance of the market interest rate is used as the volatility measure. The only case in which low-debt firms also react to the cross-effect by increasing investment is when the volatility measure is constructed by the variance of the unpredictable part of the first difference of the market interest rate. Nevertheless, the results are in general consistent with the evidence we obtained by using the firm-level measures of the interest rate volatility. Comparing the magnitude of the cross-effect

Table 4

Fixed effects estimation results: high-debt firms

$$\frac{I_t}{K_t} = f_j + f_i + \beta_1 i_t + \beta_2 \text{Var}(i_t) \times B_t + \beta_3 \text{Var}(i_t) + \beta_4 B_t + \varepsilon_t$$

Regressor	Firm interest rate		Market interest rate	
	Measure 1	Measure 2	Measure 3	Measure 4
i_t	−0.0201 <−12.9596> −0.2322	−0.0169 <−12.3177> −0.1952	−0.0172 <−12.9515> −0.1987	−0.0184 <−12.2393> −0.2126
$\text{Var}(i_t) * B_t$	5.20E−09 <5.7365> 0.2796	−3.18E−11 <−0.2205> 0.0807	5.95E−08 <6.4953> 0.0692	1.44E−08 <1.8450> 0.0165
$\text{Var}(i_t)$	−0.0011 <−0.3071> 0.0807	0.0069 <3.5003> 0.0188	0.3716 <3.3077> 0.0188	0.0224 <0.4921> 0.0188
B_t	−9.30E−09 <−9.5054> −0.2541	−7.94E−09 <−7.1130> −0.2169	−1.03E−08 <−9.2977> −0.2814	−6.76E−09 <−4.4525> −0.1847
Coefficient test (Wald)	$\beta_2 = \beta_3 = 0$	$\beta_2 = \beta_3 = 0$	$\beta_2 = \beta_3 = 0$	$\beta_2 = \beta_3 = 0$
F-statistic	53.1158**	9.7097**	48.6899**	2.4048
Adjusted R-squared	0.6237	0.6021	0.6161	0.6045

Data source: *Jaarboek van Nederlands Ondernemingen*.

The number of firms in the sample is 41, the sample period is 1984–1995.

White heteroskedasticity-consistent *t*-statistics are in brackets.Bold figures below *t*-statistics are the standardized regression coefficients.

Measure 1: The variance of the unpredictable part of the firm interest rate. Measure 2: The variance of the firm interest rate. Measure 3: The conditional variance of the market interest rate from estimating the ARCH(1) model. Measure 4: The variance of the unpredictable part of the first difference of the market interest rate.

Explanations of variables: I/K : the investment-to-capital ratio; i : the interest rate; B : debt; $\text{Var}(i)$: the variance of the interest rate.

** Significant at the 1% level.

between two subgroups, we notice that on average a 1 standard deviation increase in the cross-effect leads to 0.12 standard deviation increase in the investment-to-capital ratio for high-debt firms,⁷ while an increase in the interactive term of 1 standard deviation implies a decrease in the investment-to-capital ratio by 0.01 standard deviations for low-debt firms. These results confirm that firms react to the cross-effect of debt and the interest rate uncertainty differently, depending on the debt position of the firm. For all levered firms, the debt revaluation effect may offset the effect of the interest burden when the interest rate volatility is high. Moreover, the debt revaluation effect is obviously more important for highly indebted firms than for less-indebted firms.

⁷ Notice that this figure is larger than the average magnitude of the cross-effect when all firms are pooled together as shown by Table 3.

Table 5

Fixed effects estimation results: low-debt firms

$$\frac{I_t}{K_t} = f_j + f_i + \beta_1 i_t + \beta_2 \text{Var}(i_t) \times B_t + \beta_3 \text{Var}(i_t) + \beta_4 B_t + \varepsilon_t$$

Regressor	Firm interest rate		Market interest rate	
	Measure 1	Measure 2	Measure 3	Measure 4
i_t	–0.0275 <–9.4108> –0.3754	–0.0279 <–9.4971> –0.3808	–0.0294 <–9.6442> –0.4013	–0.0313 <–11.1689> –0.4272
$\text{Var}(i_t) \times B_t$	–8.29E–09 <–2.3428> –0.1339	–6.24E–09 <–3.5848> –0.1342	1.19E–07 <1.4998>	2.33E–07 <5.4018> 0.2248
$\text{Var}(i_t)$	0.0079 <2.0420> 0.1417	0.0053 <1.4020>	–0.5005 <–1.5868>	–0.4565 <–3.9426> –0.0829
B_t	1.10E–08 <3.6999> 0.2743	1.65E–08 <4.1027> 0.4114	3.67E–09 <0.9069>	1.47E–08 <2.8960> 0.3665
Coefficient test (Wald)	$\beta_2 = \beta_3 = 0$	$\beta_2 = \beta_3 = 0$	$\beta_2 = \beta_3 = 0$	$\beta_2 = \beta_3 = 0$
F-statistic	3.9063*	6.5399**	1.4919	14.6646**
Adjusted R-squared	0.7677	0.7636	0.7551	0.7799

Data source: *Jaarboek van Nederlands Ondernemingen*.

The number of firms in the sample is 41, the sample period is 1984–1995.

White heteroskedasticity-consistent t -statistics are in brackets.Bold figures below t -statistics are the standardized regression coefficients.

Measure 1: The variance of the unpredictable part of the firm interest rate. Measure 2: The variance of the firm interest rate. Measure 3: The conditional variance of the market interest rate from estimating the ARCH(1) model.

Measure 4: The variance of the unpredictable part of the first difference of the market interest rate.

Explanations of variables: I/K : the investment to capital ratio; i : the interest rate; B : debt; $\text{Var}(i)$: the variance of the interest rate.

* Significant at the 5% level.

** Significant at the 1% level.

With regard to the own effect of the interest rate uncertainty on investment, as shown by Tables 3–5, there is no clear-cut conclusion with respect to the sign of the uncertainty effect. This result is not surprising. It shows that the sign of the uncertainty effect is not only subject to different uncertainty measures but also to different characteristics of firms and probably the source of uncertainty. This can be explained by the fact that there are many factors that influence the investment–uncertainty relationship.⁸ Besides the issue of the risk attitude of the firm (Aizenman and Marion, 1999; Nickell, 1978), the compet-

⁸ In the investment model, we derived in Section 2, the risk-averse attitude is assumed, indicating a theoretical negative uncertainty effect if other factors are ignored. The mixed sign of the effect of the interest rate uncertainty found in empirical analyses suggests that there are indeed some other factors that affect the relationship between investment and the interest rate uncertainty.

itiveness in product markets in combination with the returns to scale (Caballero, 1991), the degree of irreversibility (Dixit and Pindyck, 1994; Abel and Eberly, 1999), the financial conditions of the firm (Greenwald and Stiglitz, 1990), and the source of uncertainty (Huizinga, 1993) are in fact interacted with each other in affecting the investment–uncertainty relationship.

Nevertheless, we do obtain a clear-cut conclusion with respect to the relationship between investment and debt as shown by Tables 4 and 5. Uniformly, the increases in debt make highly indebted firms cut investment effectively due to the increased financial burden. One standard deviation increase in debt implies a decrease in the investment-to-capital ratio by 0.23 standard deviations for high-debt firms. On the other hand, an increase in debt of 1 standard deviation suggests an increase in the investment undertaken by less-indebted firms by 0.35 standard deviations. This result indirectly confirms the evidence on the interactive effect between the interest rate volatility and debt. Although the debt effect alone depresses investment for highly indebted firms, taking account of the debt revaluation effect, high-debt firms increase investment when the volatility of the interest rate is high. This can only occur when the benefit from debt revaluation dominates the increase in the interest burden. On the other hand, the positive debt effect on investment is offset by the effect of higher cost of borrowing due to high volatile interest rate for less-indebted firms, leading low-debt firms to cut investment facing high interest rate volatility.

Finally, the results in Tables 4 and 5 consistently show that the effect of the level of the interest rate on investment is significant and negative. Moreover, as shown by the standardized regression coefficients the level effect of the interest rate on investment turns to be larger for less-indebted firms than for highly indebted firms.

The policy implication of the current study concerns the impact of the changes in the interest rate policy on firm investment. The frequent increases in the market interest rate do not only directly depress firm investment but also increase the firm interest rate through the balance sheet channel (Bernanke and Gertler, 1989), which leads to an additional decrease in firm investment. However, the expected policy effect may not be realized completely because of the existence of the debt revaluation effect of the interest rate uncertainty, which may offset the effect of the interest burden for levered firms, especially for high leverage firms. Therefore, especially when the analysis is at the aggregate-level, it is often found that the sensitivity of investment to the level of the interest rate is quite low. Indeed, there is some evidence that investment does not respond to the level of the interest rate at all (Chirinko, 1993).

5. Conclusions

This paper tests the interaction between the interest rate volatility and debt in affecting firm investment using a panel data set of listed Dutch firms during 1984–1995. Based on the assumption that the financial structure of the firm is relevant to the impact of the interest rate volatility on investment, we address the sensitivity of firm investment to the interest rate volatility, taking into account the effect of leverage. Dutch firm evidence shows that the fluctuations in the interest rate provide one possible

channel through which debt may affect firm investment, in addition to its direct impact on investment. We find that levered firms on average respond to the interactive effect of the interest rate volatility and debt by increasing investment expenditure. Moreover, Dutch evidence consistently shows that this positive cross-effect is more important for highly indebted firms than for less-indebted firms. We conclude that the debt revaluation effect in times of high interest rate volatility is less relevant for low-debt firms as compared to the effect of the increased cost of borrowing. On the other hand, the effect of the interest burden may be offset by the debt revaluation effect for highly indebted firms, which leads high-debt firms to increase investment facing high interest rate volatility.

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Appendix A

A.1. The derivation of the investment model

The intertemporal investment decision of a firm is characterized by the following optimization problem:

$$\text{Max } V_j(0) = \int_0^{\infty} e^{-rt} [E_0(\text{CF}_{jt}) - \theta \text{Var}(\text{CF}_{jt})] dt \quad (\text{A1})$$

$$\text{s.t. } \dot{K}_t = I_t - \delta K_{t-1} \quad (\text{A2})$$

$$\text{CF}_t \equiv p_t F(K_t, L_t) - w_t L_t - p_t A(K_t, I_t) - p_t I_t - i_t B_t(I_t, IW_t) + \delta K_{t-1} \quad (\text{A3})$$

where $V(0)$ is the discounted present value of the firm at time $t=0$. E_0 is the expectation operator based on the information available at time $t=0$. r is the constant discount rate faced by the firm, which is measured in real terms. CF_{jt} is the cash flow generated by firm j at time t . $\text{Var}(\text{CF}_{jt})$ is the variance of cash flow in period t , which is the measure of the amount of the risk that is associated with future income stream. θ is the market price of risk. $F(K_t, L_t)$ is the production function. K_t , L_t , and I_t are the capital stock, the labor input, and the gross investment of the firm at time t , respectively. δ is the constant rate of depreciation of capital. w_t and p_t are the nominal wage rate and the output price. $A(K_t, I_t)$ is the internal convex cost function of adjusting the capital stock. $B_t(I_t, IW_t)$ is the net borrowing of the firm at time t . i_t is the interest rate at time t .

Inserting the expected value and the variance of cash flow in Eq. (A1) and utilizing Eq. (A2), we set up the Hamiltonian function for the problem:

$$H = \left\{ [p_t F(K_t, L_t) - w_t L_t - p_t A(K_t, I_t) - p_t I_t + \delta K_{t-1} - E(i_t) B_t(I_t, IW_t) - \theta \text{Var}(i_t) B_t^2(I_t, IW_t)] + \mu(I_t - \delta K_{t-1}) \right\} e^{-rt} \quad (\text{A4})$$

Where $\text{Var}(i_t)$ is the variance of the interest rate. We assume that the adjustment cost function takes the conventional quadratic form given by:

$$A(I_t, K_t) = \alpha_1 I_t + \alpha_2 \frac{I_t^2}{K_t} \quad (\text{A5})$$

Where α_1, α_2 are constants and $\alpha_2 > 0$.

We further assume that the net borrowing of the firm is linear in the current period investment. Consequently, no matter the specification of the borrowing function, we have:

$$\frac{\partial B_t(I_t, IW_t)}{\partial I_t} = \lambda, \quad \text{where } 0 < \lambda < 1 \quad (\text{A6})$$

Inserting Eq. (A5) into Eq. (A4), using Eq. (A6) and utilizing the realizations of the interest rate as a proxy for its expected value $E(i_t) = i_t$, we obtain the first-order condition of the problem:

$$\frac{I_t}{K_t} = \frac{-(1 + \alpha_1) + \frac{\mu}{p_t}}{2\alpha_2} - \frac{\lambda}{2\alpha_2 p_t} i_t - \frac{\theta \lambda}{\alpha_2 p_t} \text{Var}(i_t) \times B_t \quad (\text{A7})$$

Normalizing the price of goods and redefining the parameters, Eq. (A7) becomes:

$$\frac{I_t}{K_t} = \beta_0 + \beta_1 i_t + \beta_2 \text{Var}(i_t) \times B_t + \varepsilon_t \quad (\text{A8})$$

where ε is the error term. It is good to note that the first parameter contains both the Q-effect and an intercept. The sign of β_0 is unknown. $\beta_1 < 0$ since $\alpha_2 > 0$ and $\lambda > 0$. $\beta_2 < 0$ since $\alpha_2 > 0$, $\lambda > 0$, and $\theta > 0$.

Appendix B

B.1. Data description

The main data source is the publication of *Jaarboek van Nederlandse Ondernemingen*. The firms in the data set are listed on the Amsterdam stock exchange over the period of 1984–1995. We construct a balanced panel of 82 manufacturing firms. We use:

Investment (I) = capital goods investment, which is the sum of the changes in the capital stock and the depreciation of the capital stock.

Capital stock (K) = the book value of the capital stock.

Firm interest rate (i)=the firm ex-post interest rate, which is calculated by the ratio of the interest payments to the book value of debt (short plus long-term debt).

Debt (B)=the book value of debt (short plus long-term debt).

The 10-year government bond rate is taken from the publications of the De Nederlandse Bank.

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